

The Role of R&D in the Age of Renewable Energy

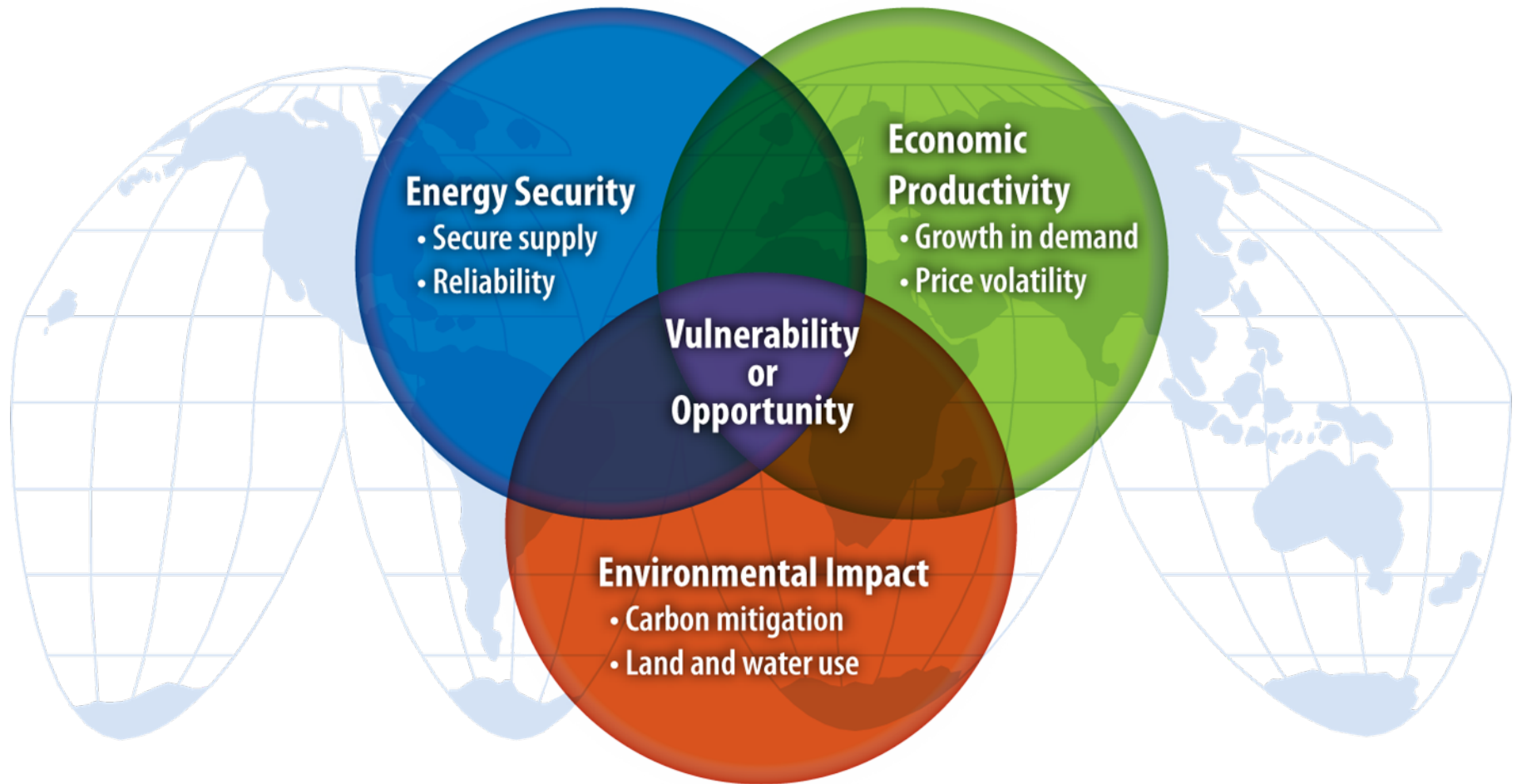


**Presented to the Institute
for Human and Machine
Cognition**

**Dr. Dan E. Arvizu
Laboratory Director**

September 9, 2008

Energy Solutions Are Enormously Challenging



Must address all three imperatives

Mounting Evidence



Mounting Evidence

\$125

Oil Prices Dollars Per Barrel

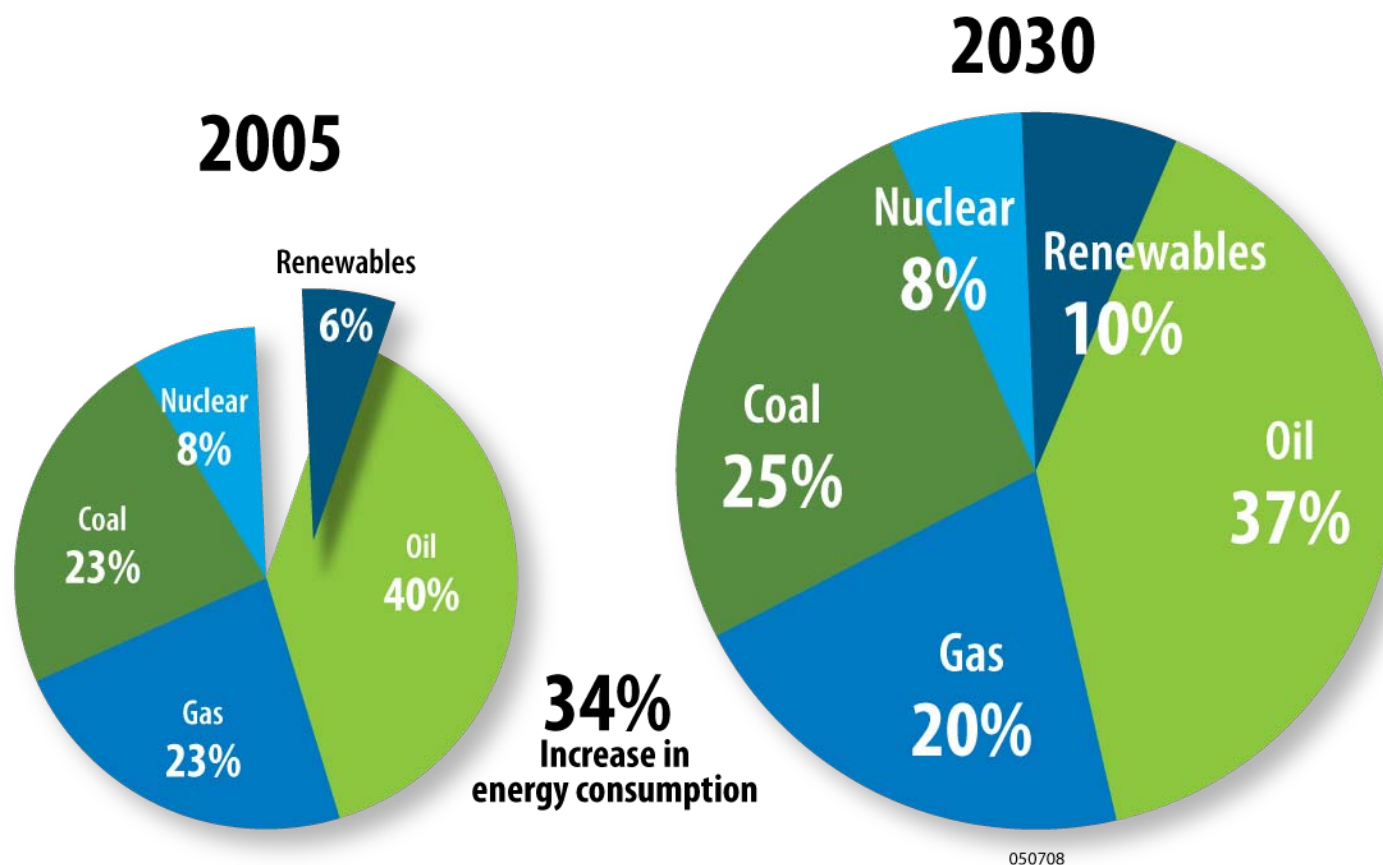
\$0

1970

2008



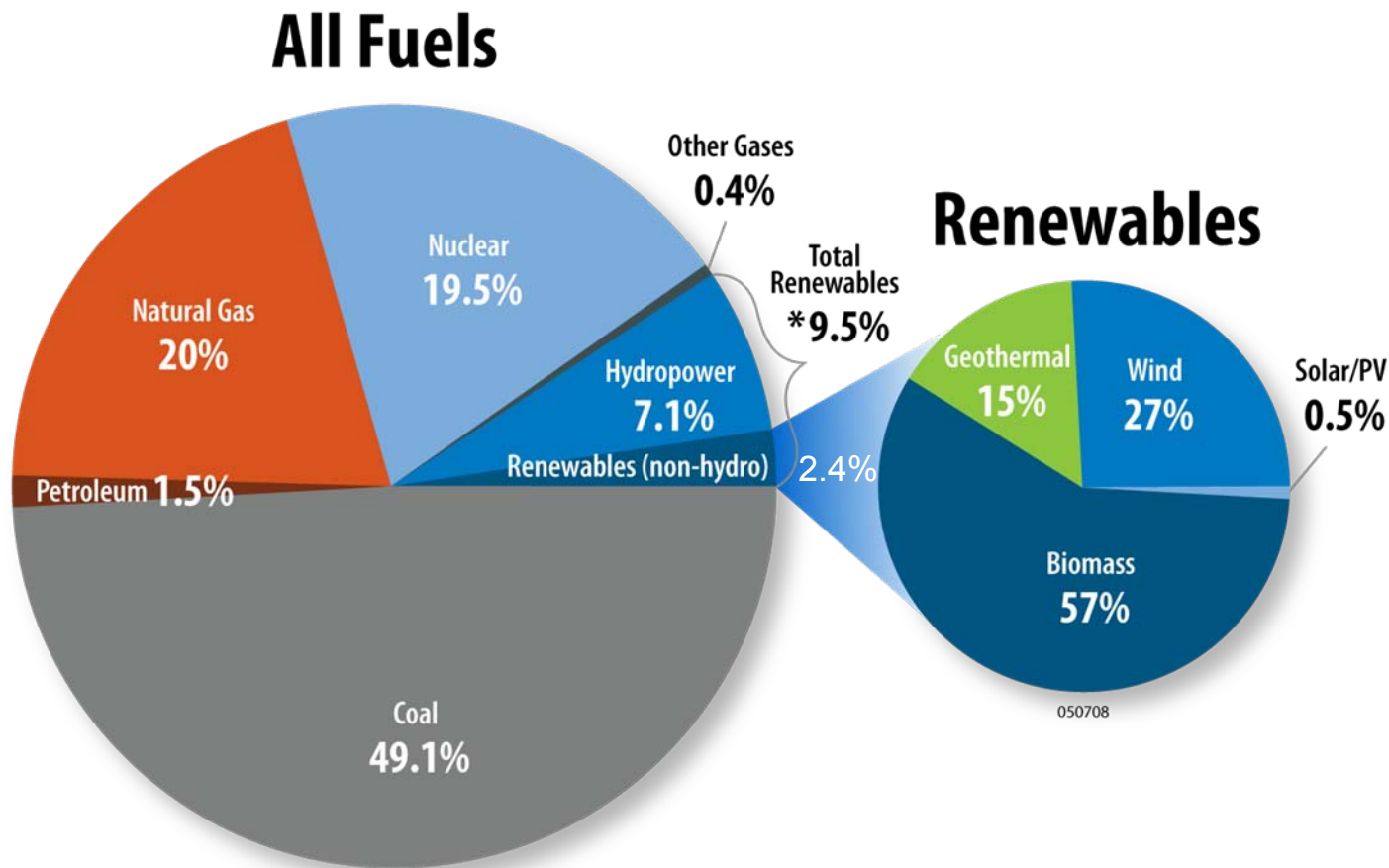
U.S. Energy Consumption and the Role of Renewable Energy



Source: Energy Information Administration,
Annual Energy Outlook 2008 (revised early release), Table 1

What Are the Major Renewables?

U.S. Electricity Net Generation

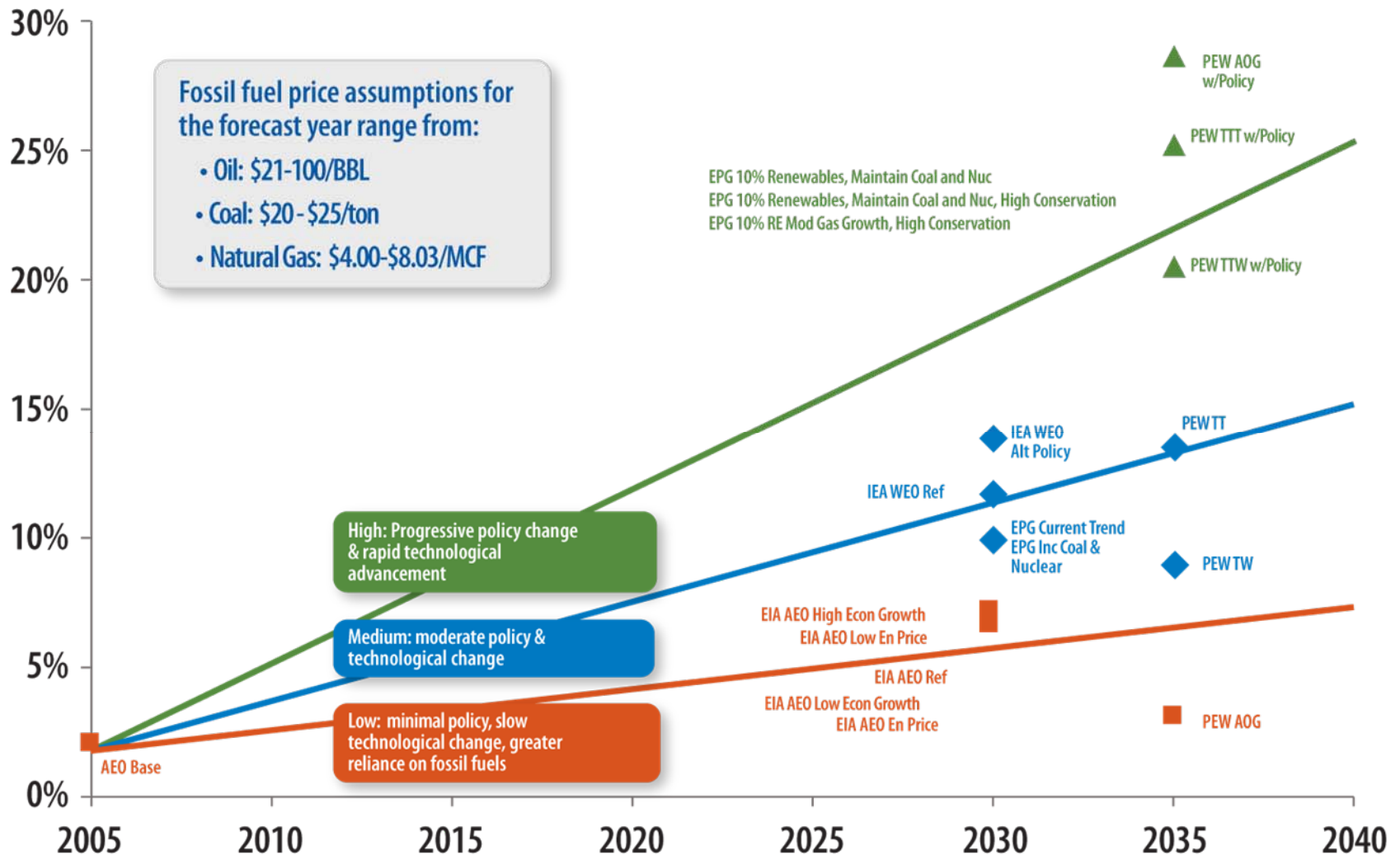


Net generation for 2006 = 3814 TWhr UCb

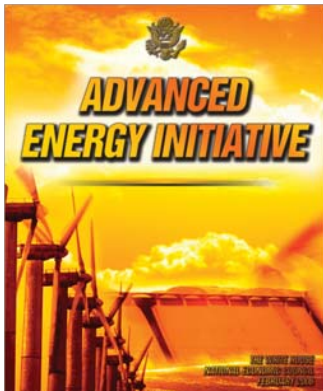
Source: EIA Annual Energy Review 2007, AEO 2008

U.S. Renewable Energy Contributions

Percent of Total Electric Generating Capacity

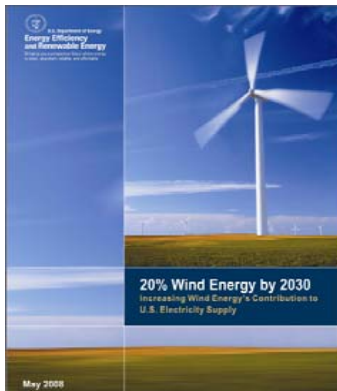


Setting the Bar Higher – Gigawatt-Scale Renewables



Solar Vision

*10% U.S. electricity
by 2025*



Wind Vision

*20% U.S. electricity
by 2030*



Energy Independence & Security Act 2007

*36 billion gallons of renewable
fuels by 2022*

Requires investment in new infrastructure:

- Overall in U.S. = \$2 trillion
- Worldwide = \$22 trillion
- Biofuels
 - Wind
 - Solar

} \$2 trillion (est.)

Getting to “Speed and Scale” – Key Challenges

Implementing Renewable Gigawatts at Scale



NREL 140-1

**B
A
R
R
I
E
R
S**

- Cost of renewable electricity
- Performance and reliability
- Infrastructure robustness and capacity
- Dispatchability of renewables

Displacement of Petroleum-Based Fuels



NREL 139-1

**B
A
R
R
I
E
R
S**

- Cellulosic ethanol cost
- Life cycle sustainability of biofuels
- Fuels infrastructure, including Codes/Standards
- Demand and utilization, including intermediate blends

Reducing Energy Demand of Buildings, Vehicles, and Industry



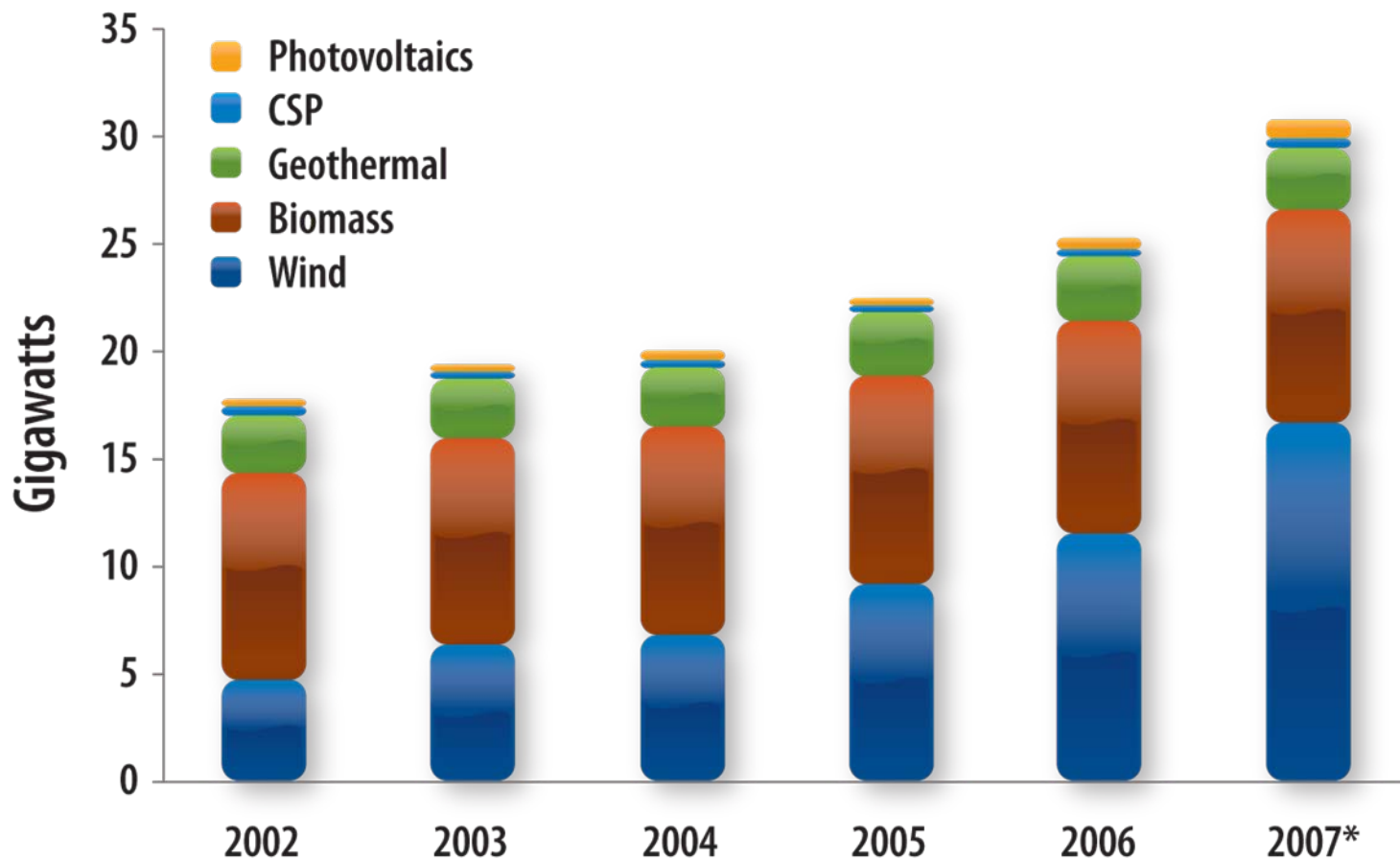
NREL 196-1

**B
A
R
R
I
E
R
S**

- Coordinated implementation of model building codes
- Market does not value efficiency
- Cost of energy efficient technologies
- Performance and reliability of new technologies

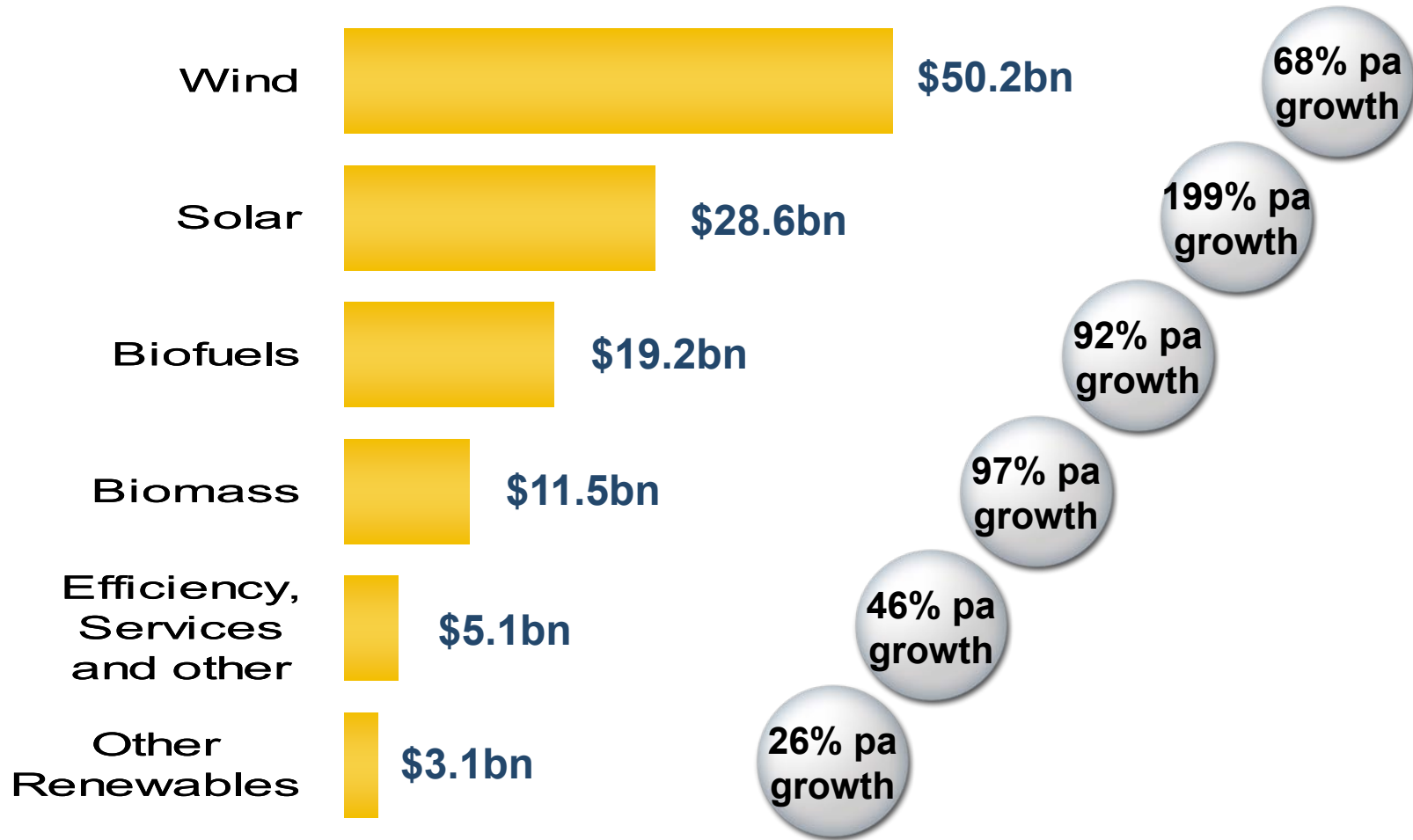
Dynamic External Environment is Accelerating Speed and Scale of Renewable Energy

U.S. Renewable Electricity Installed Nameplate Capacity



Sources: Chalk, AWEA, IEA, NREL, EIA, GEA

New Investment 2007 and Average Growth 2005-07 – By Sector



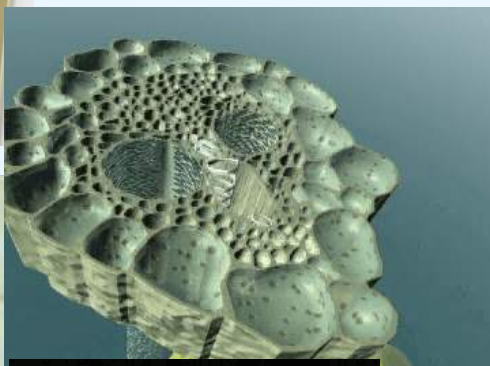
Note: VC/PE, Public Markets and Asset Finance only. Excludes re-investment adjustment

Source: New Energy Finance

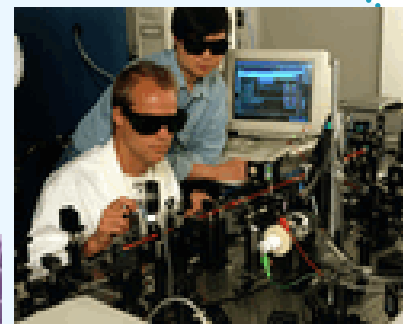
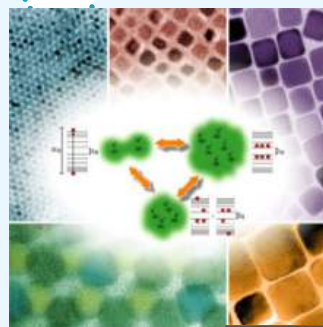
Translational Science is Key to Speed and Scale



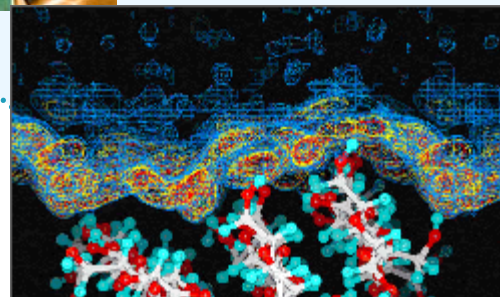
Systems Biology



Computational Science



Photoconversion



**Connecting new discoveries, via applied research,
to the marketplace**

Discovery Research

Use-inspired
Basic Research

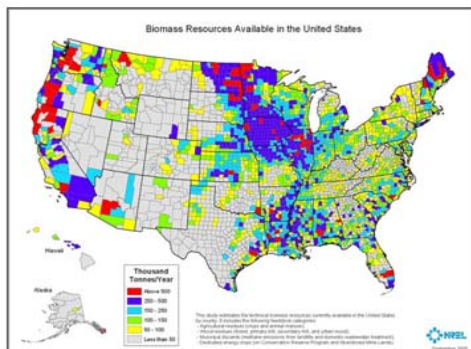
Purpose-Driven
Exploratory Research

Applied Research
& Development

Technology Maturation
& Deployment

Managing the Lab-to-Market Interface

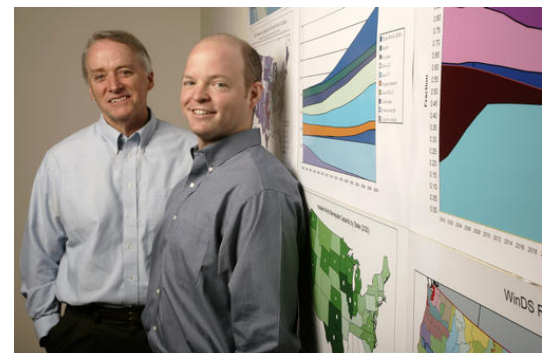
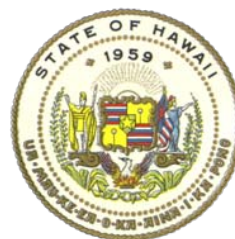
- Partner with industry, universities, other federal agencies, international community and state/local governments to deploy clean energy solutions
 - Hawaii training, DuPont CRADA, Xcel/SolarTAC
- Contribute timely and definitive analyses on technology, policy, and market issues that impact commercialization
- Provide investment community with credible information (industry growth forums)



Human Energy™



The miracles of science™



Technology Development Programs



Efficient Energy Use

- Vehicle Technologies
- Building Technologies
- Industrial Technologies



Renewable Resources

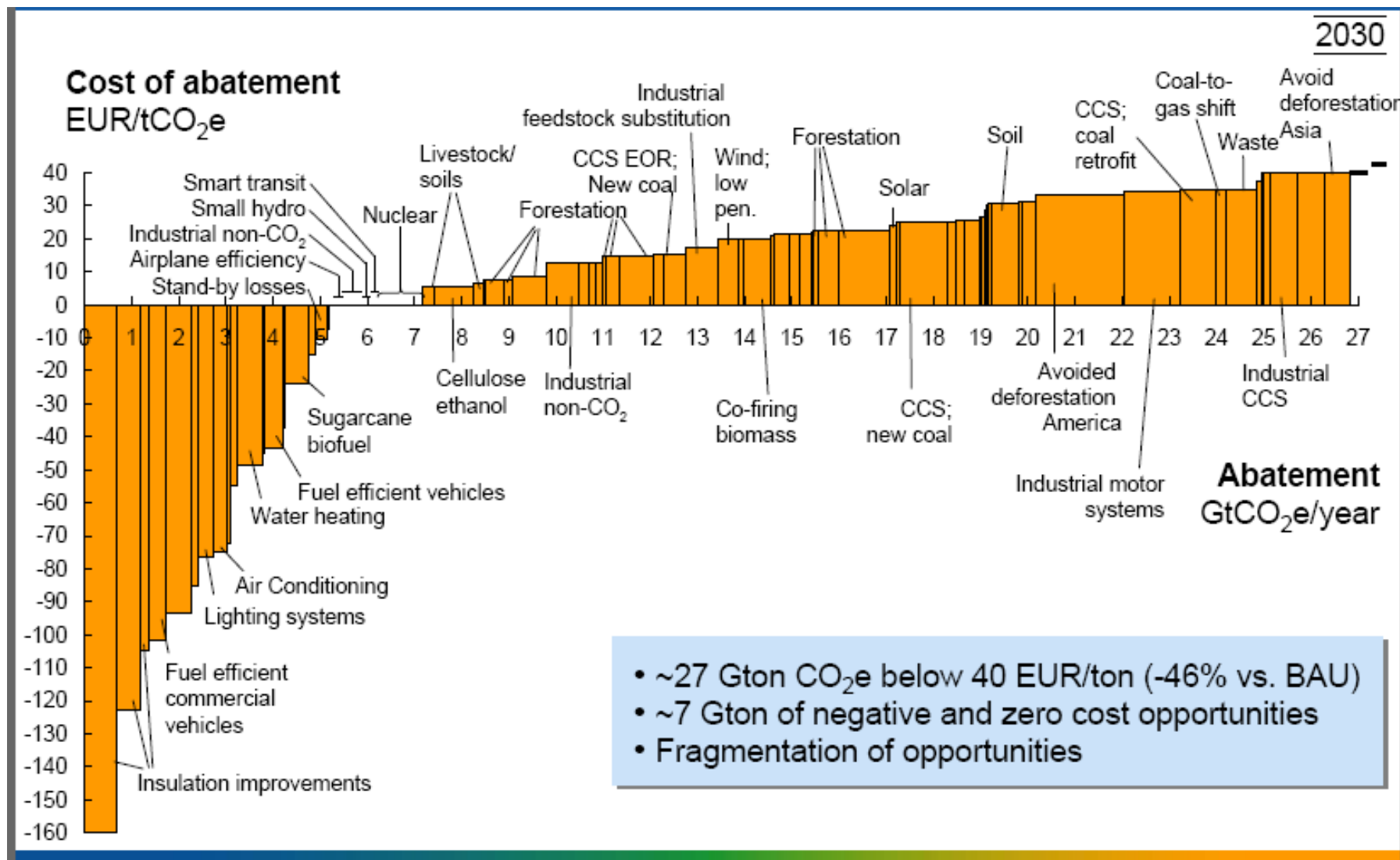
- Wind and water
- Solar
- Biomass
- Geothermal



Energy Delivery and Storage

- Electricity Transmission and Distribution
- Alternative Fuels
- Hydrogen Delivery and Storage

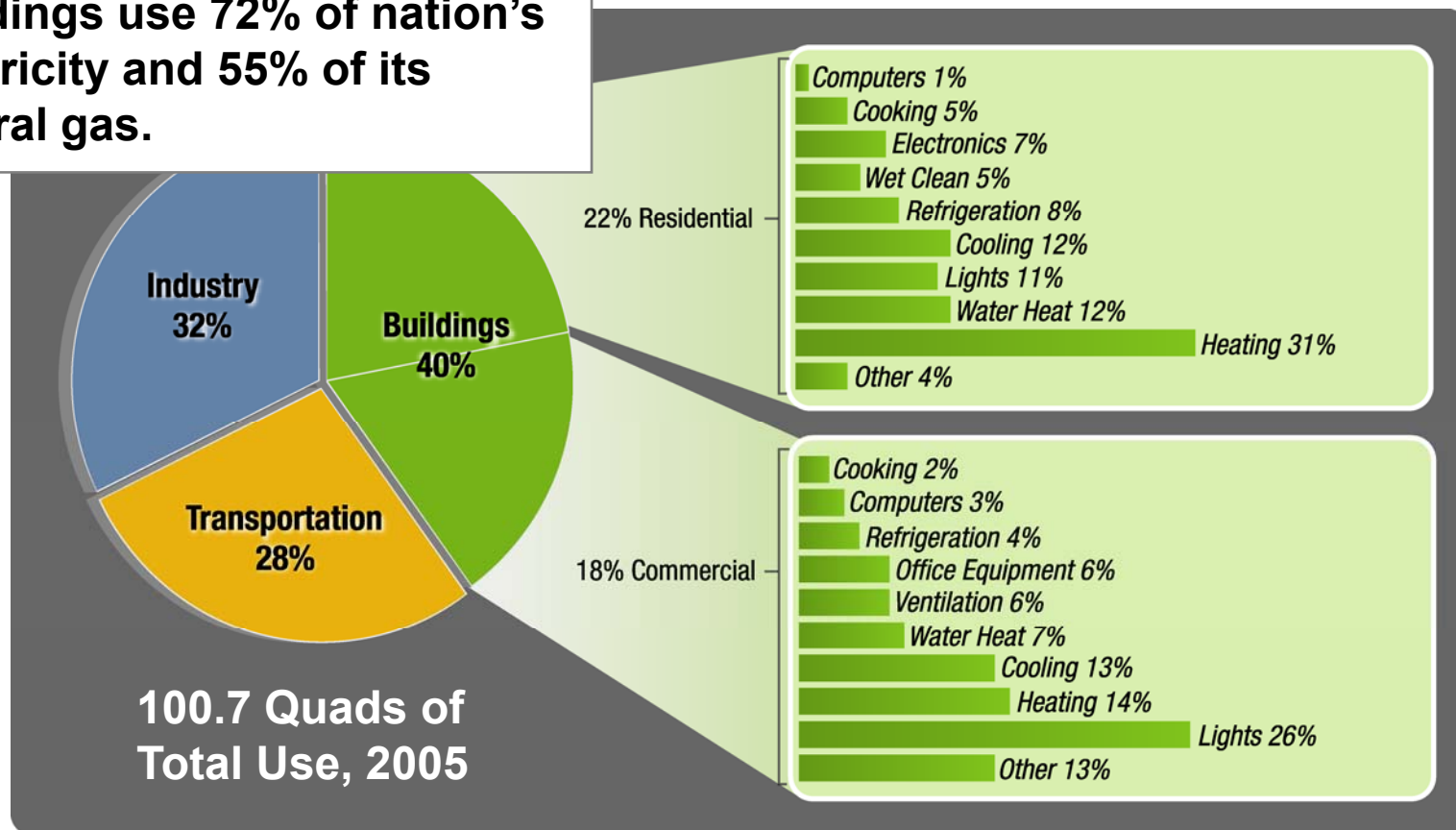
Global cost curve of GHG abatement opportunities beyond business as usual



Source: Vattenfall AB, Global Mapping of Greenhouse Gas Abatement Opportunities, 1/07

Buildings Matter

Buildings use 72% of nation's electricity and 55% of its natural gas.



Buildings construction/renovation contributed 9.5% to US GDP and employs approximately 8 million people. Buildings' utility bills totaled \$370 Billion in 2005.

Source: *Buildings Energy Data Book 2007*

Buildings

Status U.S. Buildings:

- 40% of primary energy
- 72% of electricity
- 38% of carbon emissions

DOE Goal:

- Cost effective, marketable zero energy buildings by 2025
- Value of energy savings exceeds cost of energy features on a cash flow basis

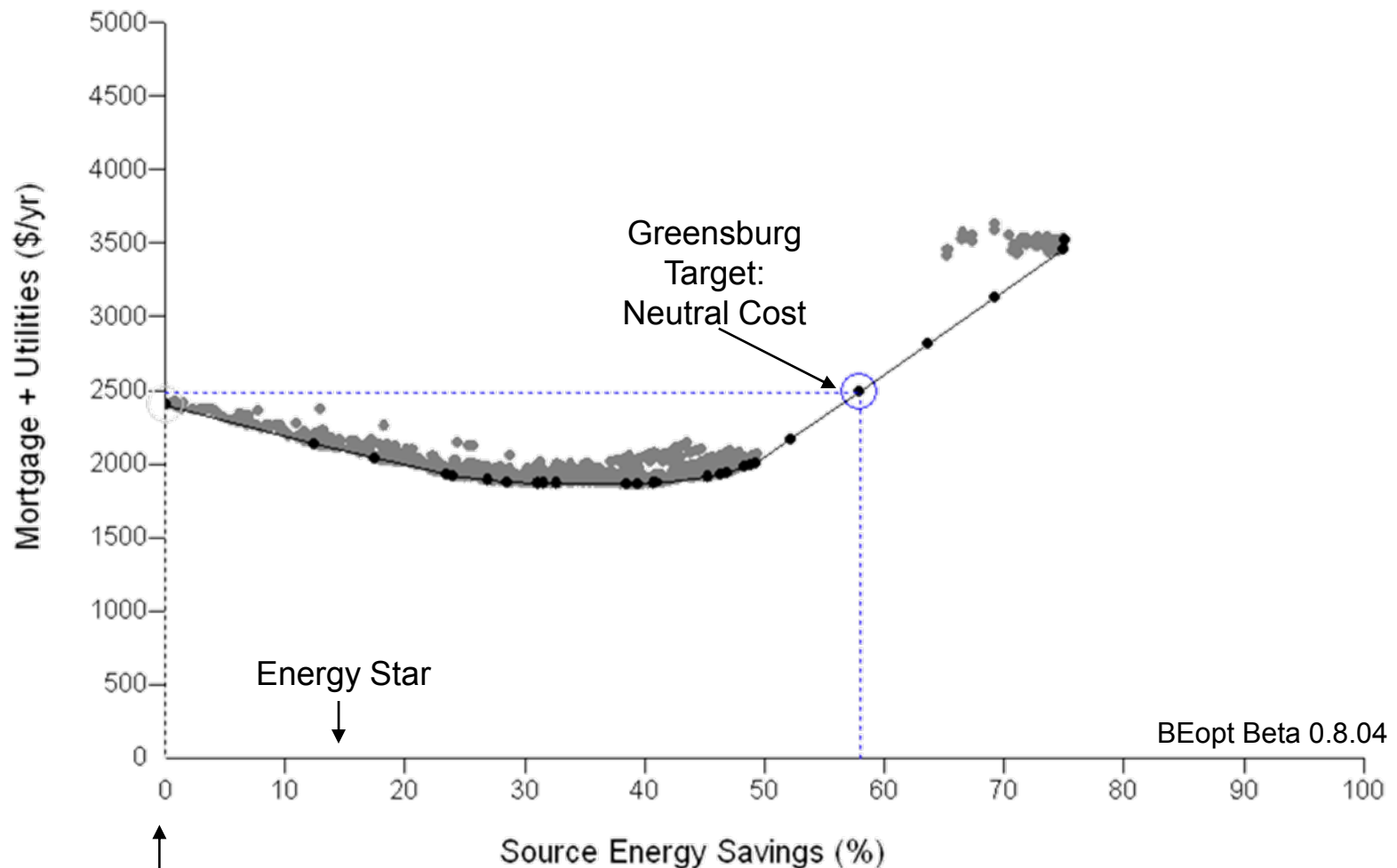
NREL Research Thrusts

- Whole building systems integration of efficiency and renewable features
- Computerized building energy optimization tools
- Advanced HVAC and envelope technologies
- Building integrated PV



Neutral Cost Point Example

Greensburg, Kansas



IECC 2003

(2000 ft², 2-story, 16% window to floor area ratio, unconditioned basement)

Plug-In Hybrid Electric Vehicles (PHEV)

Status:

- PHEV-only conversion vehicles available
- OEMs building prototypes
- NREL PHEV Test Bed

NREL Research Thrusts

- Energy storage
- Advanced power electronics
- Vehicle ancillary loads reduction
- Vehicle thermal management
- Utility interconnection
- Vehicle-to-grid

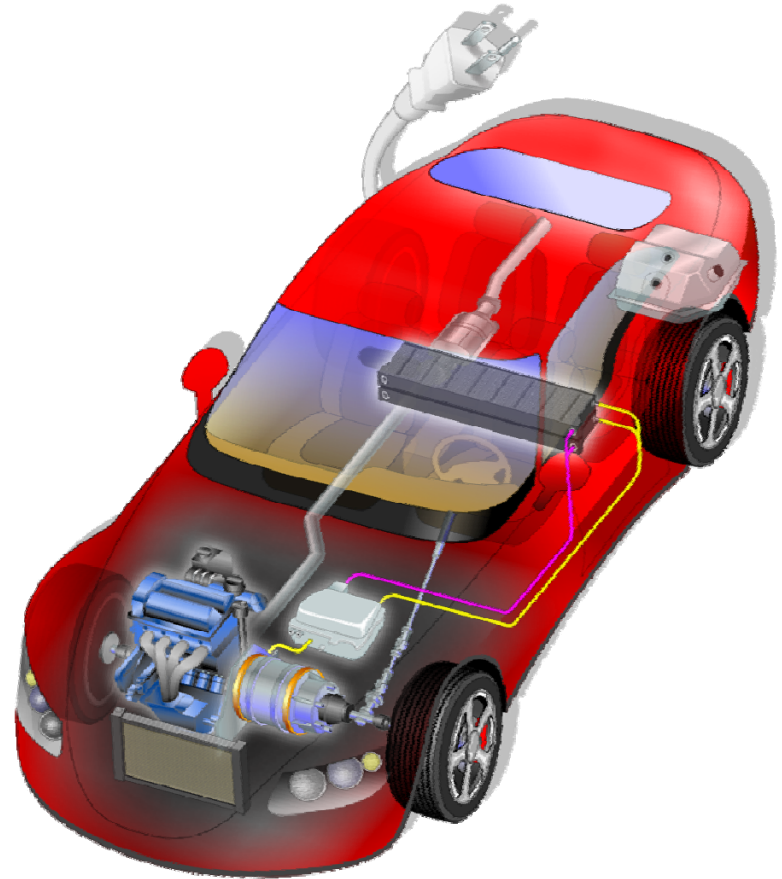
Key Challenges

- Energy storage – life and cost
- Utility impacts
- Vehicle cost
- Recharging locations
- Tailpipe emissions/cold starts
- Cabin heating/cooling
- ~33% put cars in garage

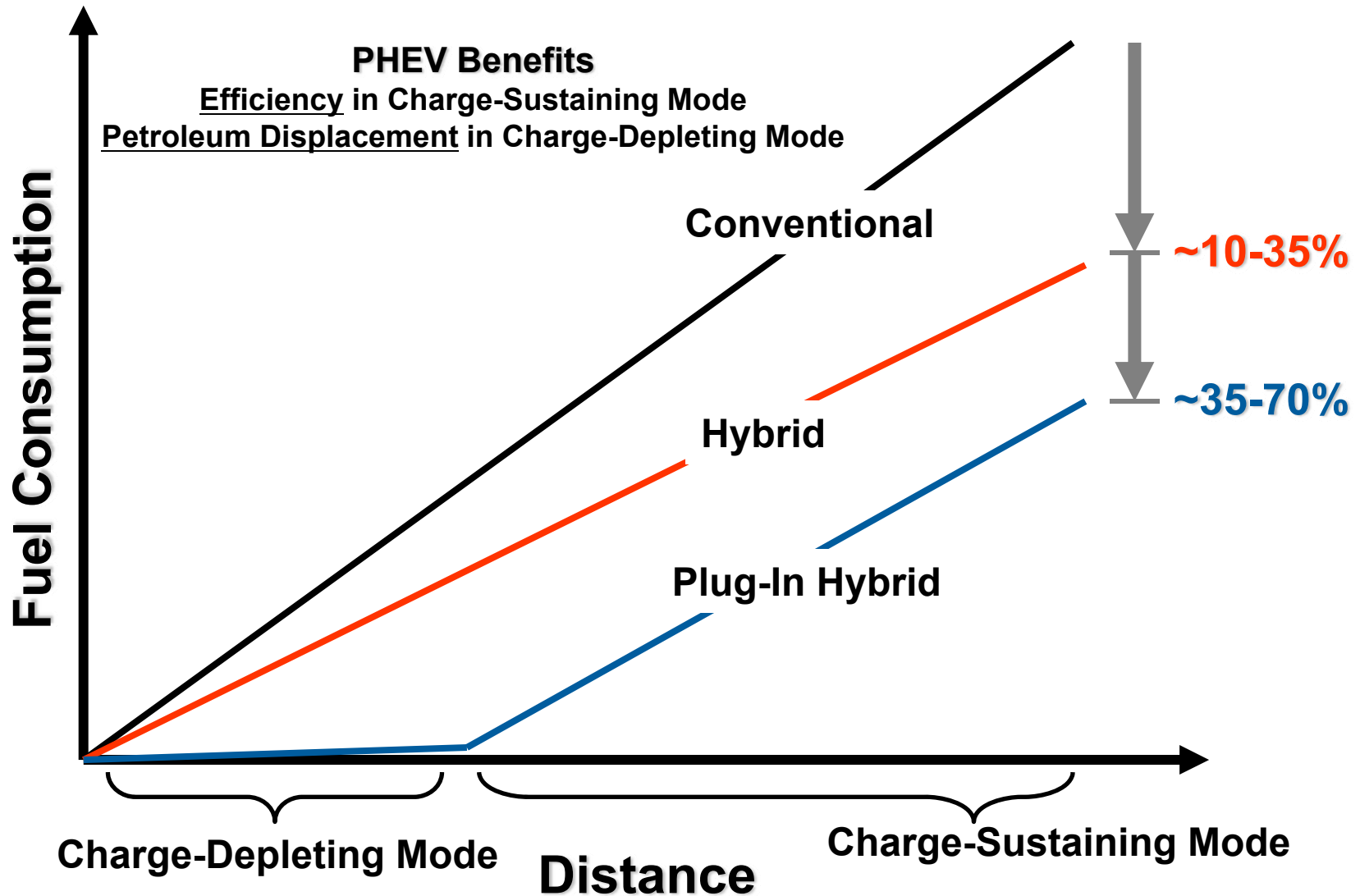


Challenges for Plug-Ins

- Improving batteries
 - Cost
 - Calendar and cycle life
 - Safety of Li-Ion
 - Cold temperature performance
 - Volume and packaging
- Reducing power electronics cost and volume
- Developing efficient chargers
- Standardizing plugs for charging
- Avoiding negative peak time charging impacts



PHEV Benefits Tied to Usage Pattern



Science at the Leading Edge of Energy Efficiency Research

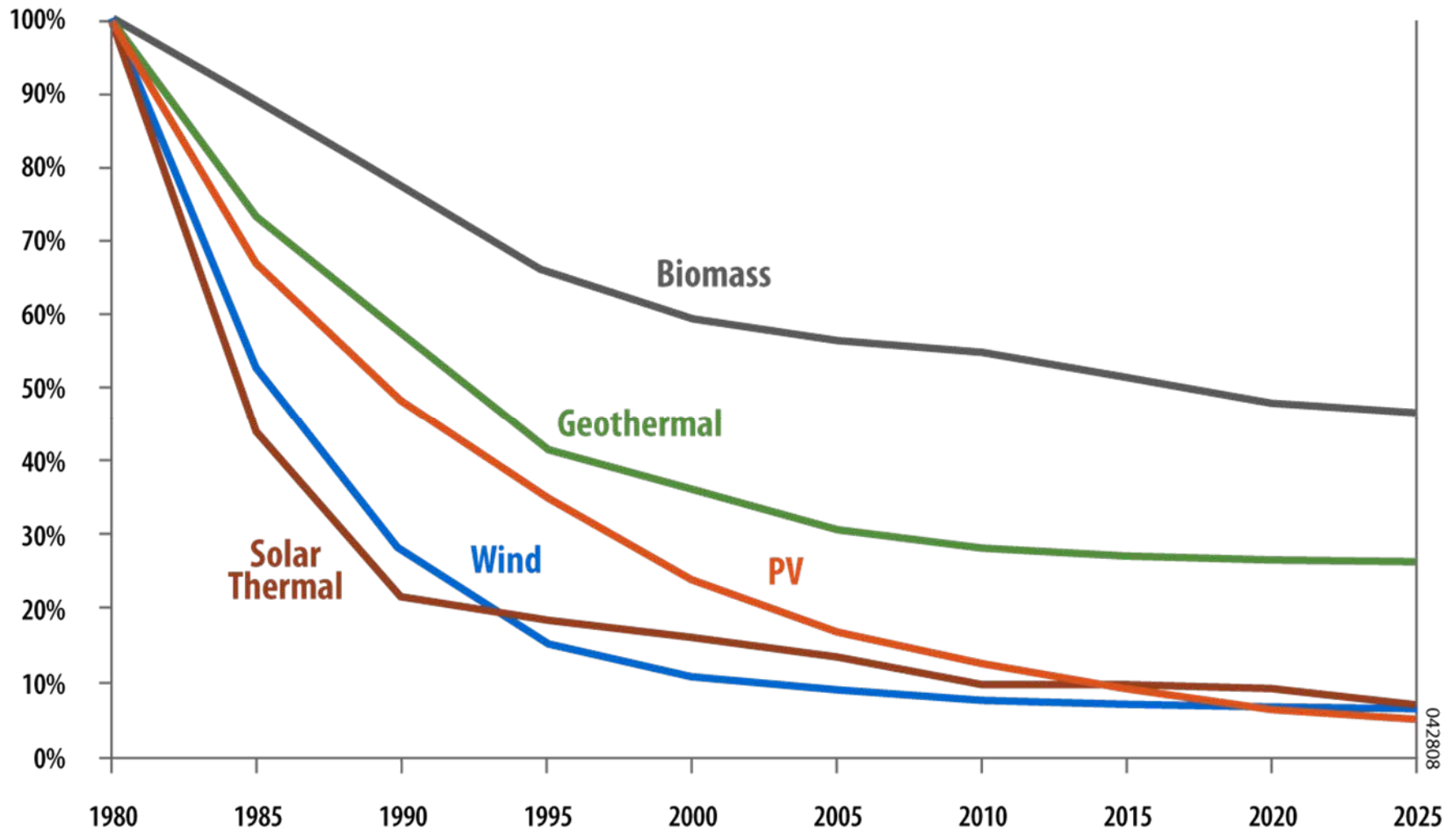
Significant improvements are anticipated through:

- Super-strong lightweight materials
- Smart roofs
- Solid state lighting
- Superconducting

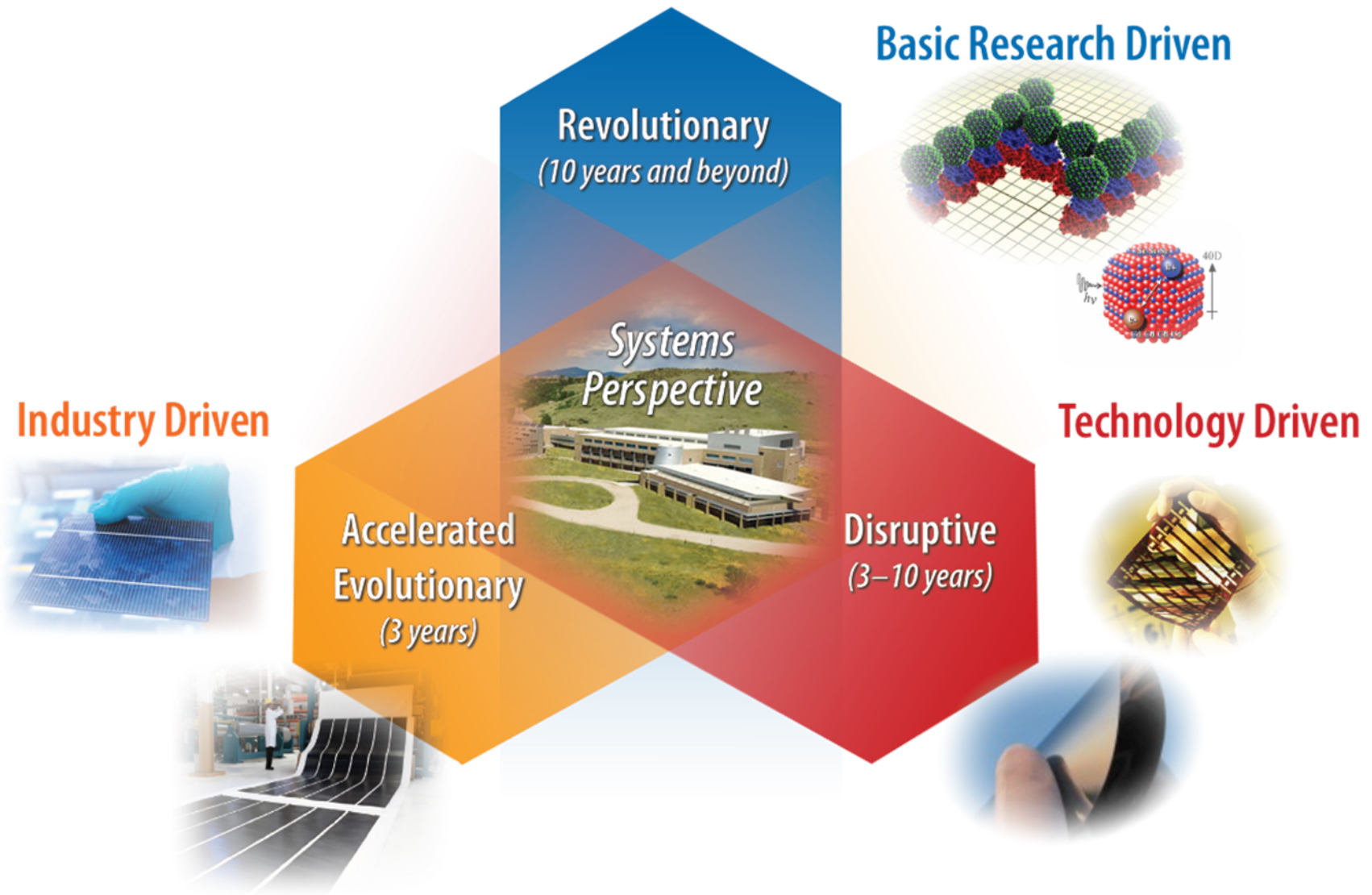
**New discoveries will have
broad impact on daily life**



Past Investments Have Dramatically Reduced Costs of Supply Options



Maxmizing Impact



Wind

Today's Status in U.S.

- 20,050 MW installed
- Cost 6-9¢/kWh at good wind sites*

DOE Cost Goals

- 3.6¢/kWh, onshore at low wind sites by 2012
- 7¢/kWh, offshore in shallow water by 2014

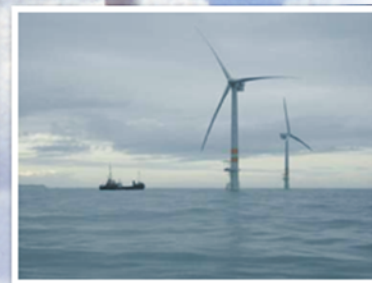
Long Term Potential

- 20% of the nation's electricity supply

* With no Production Tax Credit

Updated September 2008

Source: U.S. Department of Energy, American Wind Energy Association

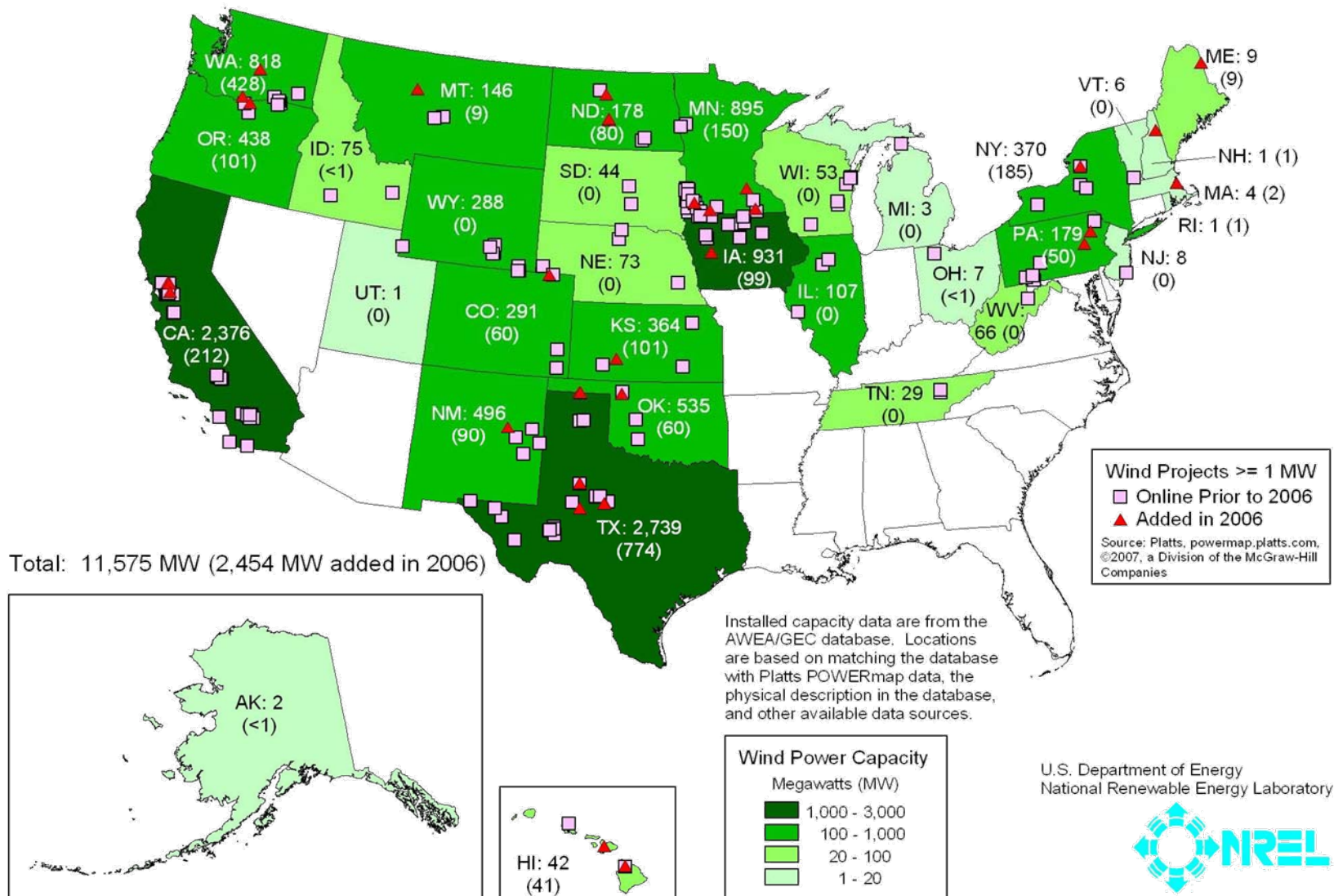


NREL Research Thrusts

- Improved performance and reliability
- Advanced rotor development
- Utility grid integration

Source: Megavind Report *Denmark's future as leading centre of competence* within the field of wind power

Installed Wind Capacity



Integrating Wind Into Power Systems

New studies find integrating wind into power systems is manageable, but not costless

Date	Study	Wind Capacity Penetration	Cost (\$/MWh)				
			Regulation	Load Following	Unit Commitment	Gas Supply	TOTAL
2003	Xcel-UWIG	3.5%	0	0.41	1.44	na	1.85
2003	We Energies	4%	1.12	0.09	0.69	na	1.90
2003	We Energies	29%	1.02	0.15	1.75	na	2.92
2004	Xcel-MNDOC	15%	0.23	na	4.37	na	4.60
2005	PacifiCorp	20%	0	1.6	3	na	4.60
2006	CA RPS (multi-year)	4%	0.45*	trace	na	na	0.45
2006	Xcel-PSCo	10%	0.2	na	2.26	1.26	3.72
2006	Xcel-PSCo	15%	0.2	na	3.32	1.45	4.97
2006	MN-MISO 20%	31%	na	na	na	na	4.41**

* 3-year average

** highest over 3-year evaluation period

Key Results from Major Wind Integration Studies Completed 2003-2006

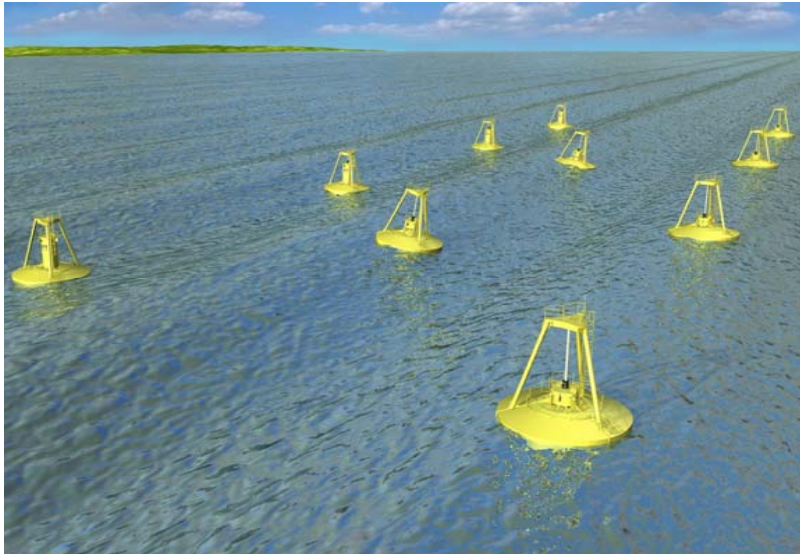
Some Additional Reserves May Need to be Committed

Reserve Category	Base		15% Wind		20% Wind		25% Wind	
	MW	%	MW	%	MW	%	MW	%
Regulating	137	0.65%	149	0.71%	153	0.73%	157	0.75%
Spinning	330	1.57%	330	1.57%	330	1.57%	330	1.57%
Non-Spin	330	1.57%	330	1.57%	330	1.57%	330	1.57%
Load Following	100	0.48%	110	0.52%	114	0.54%	124	0.59%
Operating Reserve Margin	152	0.73%	310	1.48%	408	1.94%	538	2.56%
Total Operating Reserves	1049	5.00%	1229	5.86%	1335	6.36%	1479	7.05%

Source MN DOC

Estimated Operating Reserve
Requirement for MN BAs – 2020 Load

Marine Energy



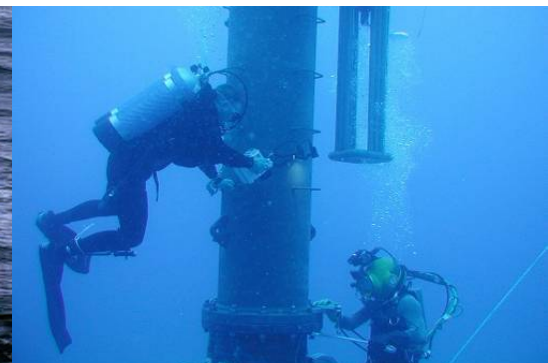
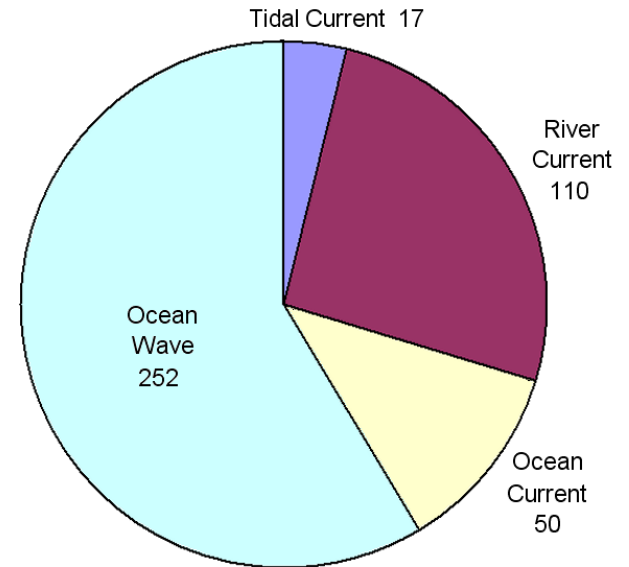
Ocean Power Technologies
Concept for 1.5-MW Wave Farm, Reedsport OR

- Companies developing marine energy increased from 35 to 81 from 2003-6
- Wave and tidal devices dominate
- Most companies are small and under capitalized
- Most are at the conceptual or scale model testing phase
- Few are in long term, full scale ocean testing phase
- No companies are in commercial production
- Federal funding: FY2008 at \$10M

Marine Energy Technical Challenges

- Resource is dispersed regionally among a few states and has not yet been fully quantified
- Regulatory barriers are impeding technology development – projects face old hydro permitting schemes
- Technology is not proven; there is no basis for evaluating different concepts.
- Environmental sensitivities & competing use impacts need to be quantified

Hydrokinetic Production Potential (TWh/yr)



Solar – Photovoltaics and CSP

Status in U.S.

PV

- 824 MW installed capacity
- Cost 18-23¢/kWh

CSP

- 419 MW installed capacity
- Cost 12¢/kWh

Potential:

PV

- 11-18¢/kWh by 2010
- 5-10 ¢/kWh by 2015

CSP

8.5 ¢/kWh by 2010

6 ¢/kWh by 2015



Source: U.S. Department of Energy, IEA
Updated January 28, 2008

NREL Research Thrusts

PV

- Higher performance cells/modules
- New nanomaterials applications
- Advanced manufacturing techniques

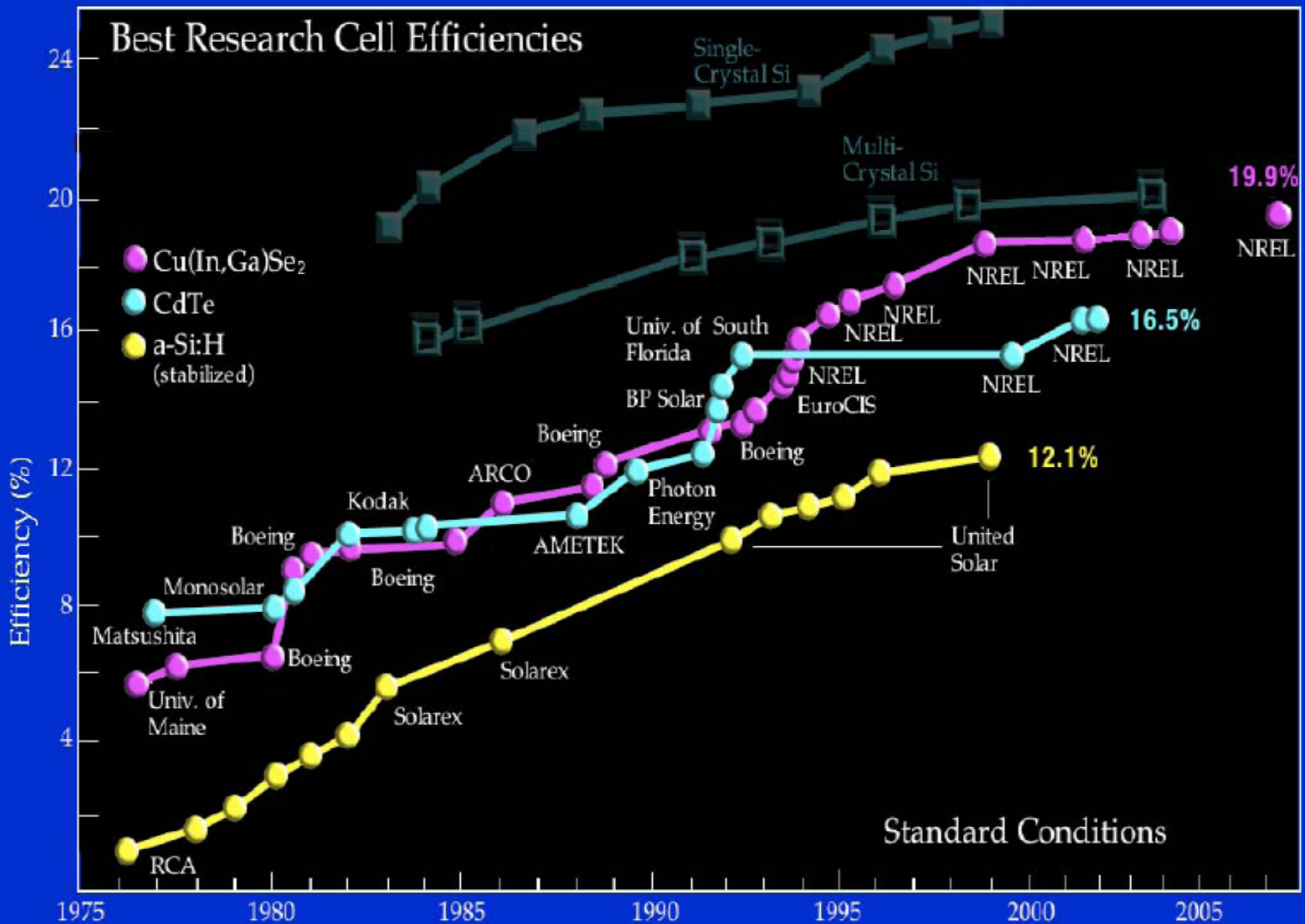
CSP

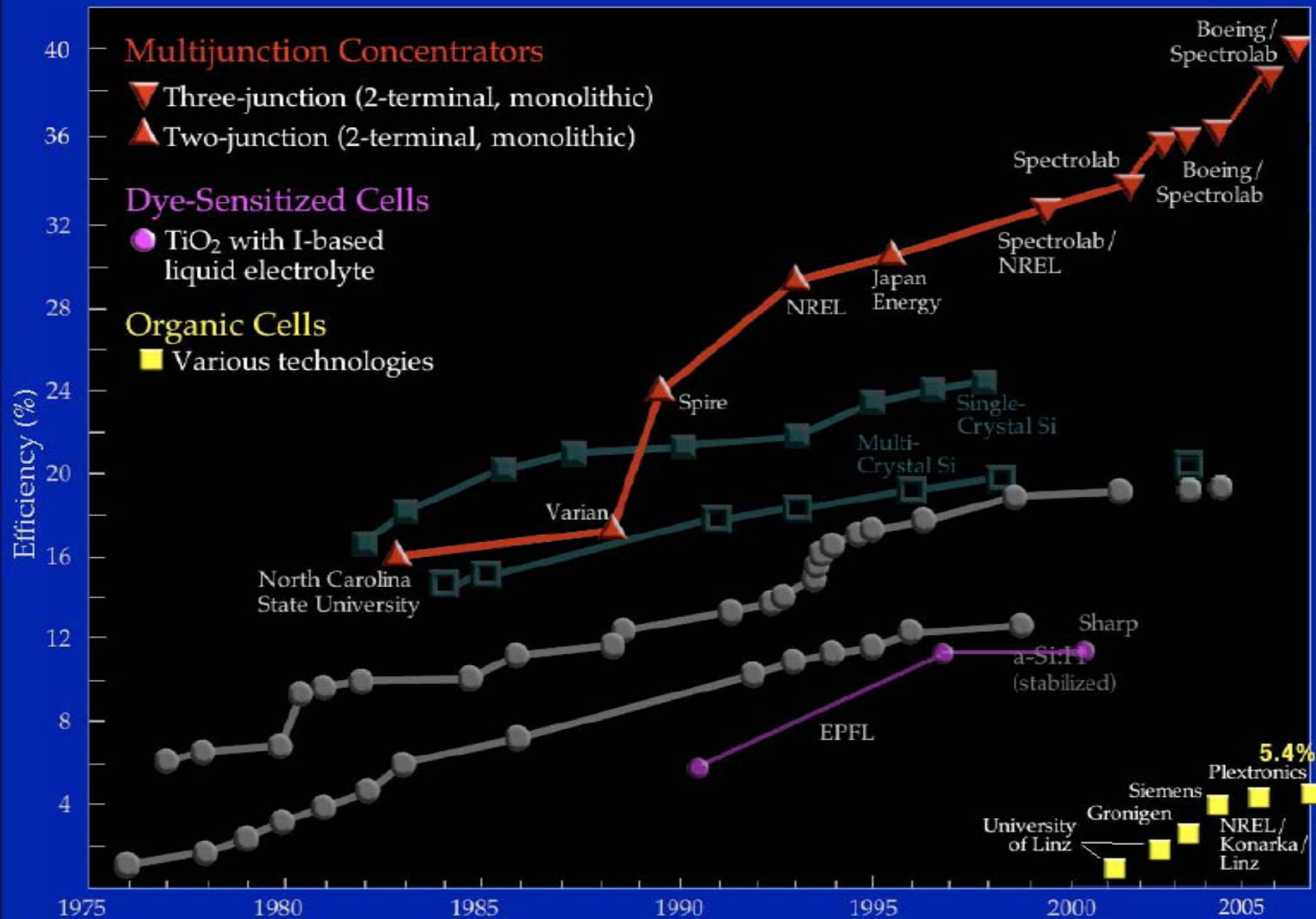
- Low cost high performance storage for baseload markets
- Advanced absorbers, reflectors, and heat transfer fluids
- Next generation solar concentrators



8.22-megawatt Alamosa, Colo., PV solar plant

Best Research Cell Efficiencies





8.22-megawatt Alamosa, Colo., PV solar plant



Geothermal

Today's Status in U.S.

- 2,800 MWe installed, 500 MWe new contracts, 3000 MWe under development
- Cost 5-8¢/kWh with no PTC
- Capacity factor typically > 90%, base load power

DOE Cost Goals:

- <5¢/kWh, for typical hydrothermal sites
- 5¢/kWh, for enhanced geothermal systems with mature technology

Long Term Potential:

- Recent MIT Analysis shows potential for 100,000 MW installed Enhanced Geothermal Power systems by 2050, cost-competitive with coal-powered generation

April 10, 2008



NREL Research Thrusts:

- Analysis to define the technology path to commercialization of Enhanced Geothermal Systems
- Low temperature conversion cycles
- Better performing, lower cost components
- Innovative materials

Biofuels

Current Biofuels Status

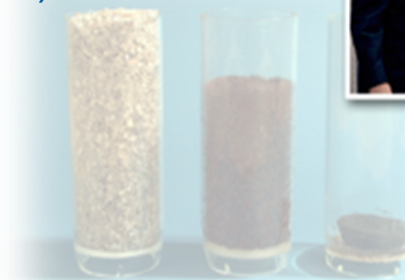
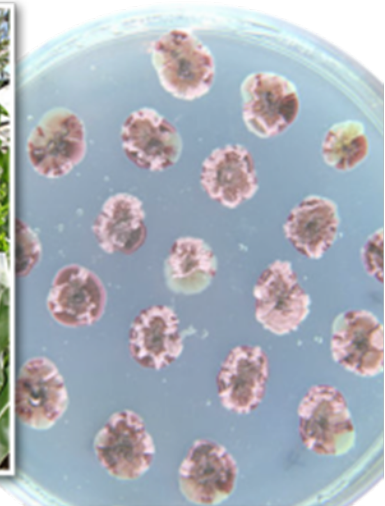
- Biodiesel – 165 companies; 1.85 billion gallons/yr capacity¹
- Corn ethanol
 - 134 commercial plants²
 - 7.2 billion gal/yr. capacity²
 - Additional 6.2 billion gal/yr planned or under construction
- Cellulosic ethanol (current technology)
 - Projected commercial cost ~\$3.50/gge

Key DOE Goals

- 2012 goal: cellulosic ethanol \$1.31/ETOH gallon or ~\$1.96/gge
- 2022 goal: 36B gal Renewable Fuel; 21B gal “Advanced Renewable Fuel”– 2007 Energy Independence and Security Act
- 2030 goal: 60 billion gal ethanol (30% of 2004 gasoline)

NREL Research Thrusts

- The biorefinery and cellulosic ethanol
- Solutions to under-utilized waste residues
- Energy crops

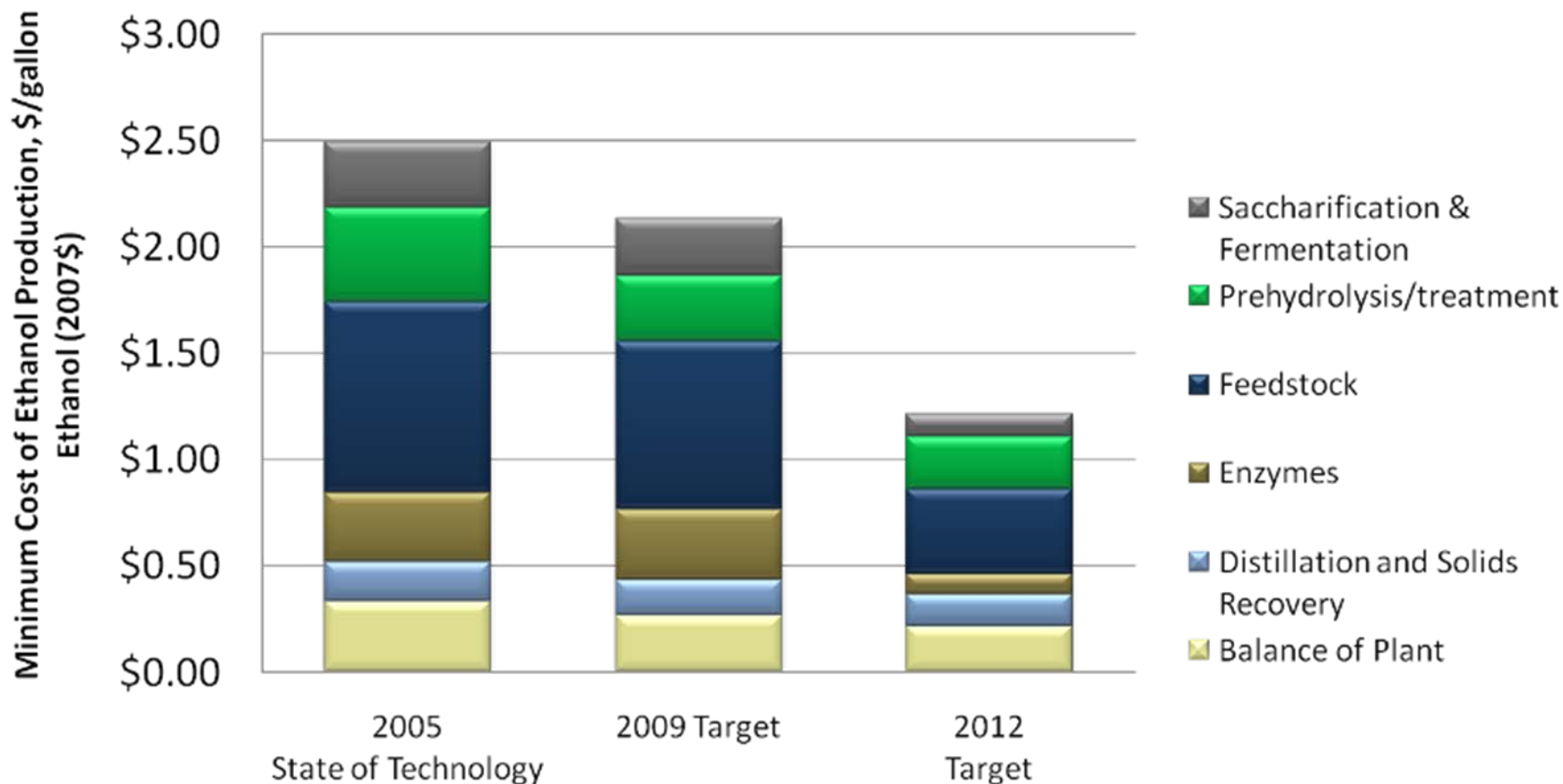


Updated February 2008

Sources: 1- National Biodiesel Board

2 - Renewable Fuels Association, all other information based on DOE and USDA sources

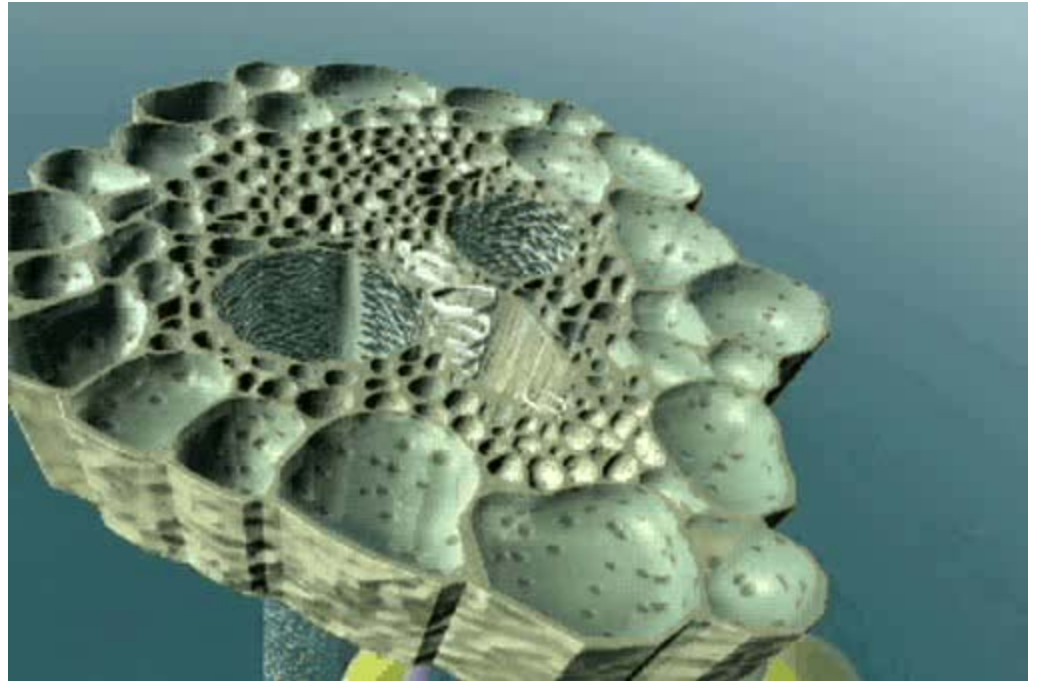
Cellulosic Ethanol Cost Goals



DOE efforts aim to trigger a substantial cost decline in the production of cellulosic ethanol

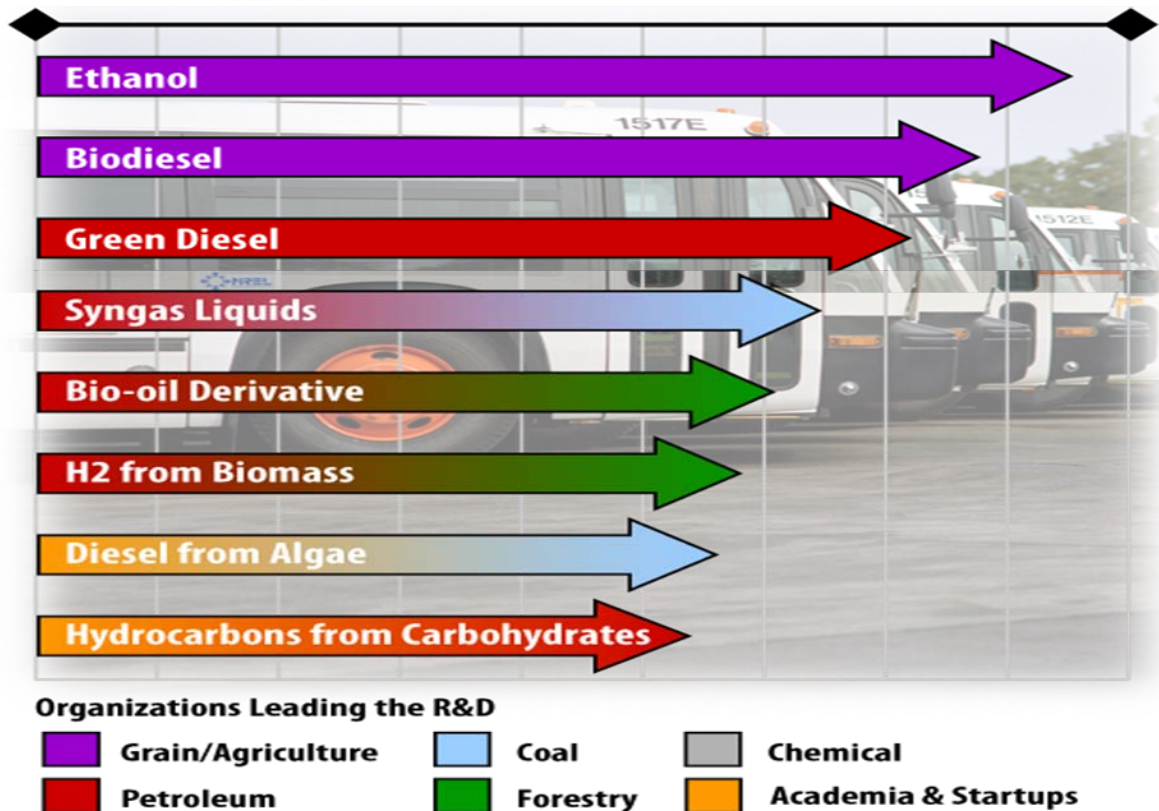
Feedstock Engineering

- Increase crop production (agronomics and plant engineering)
- Increase composition of desirable polysaccharides (cellulose)
- Decrease composition of undesirable polymers (lignins)



NREL “Corn Stem Tour”

Transportation Fuels

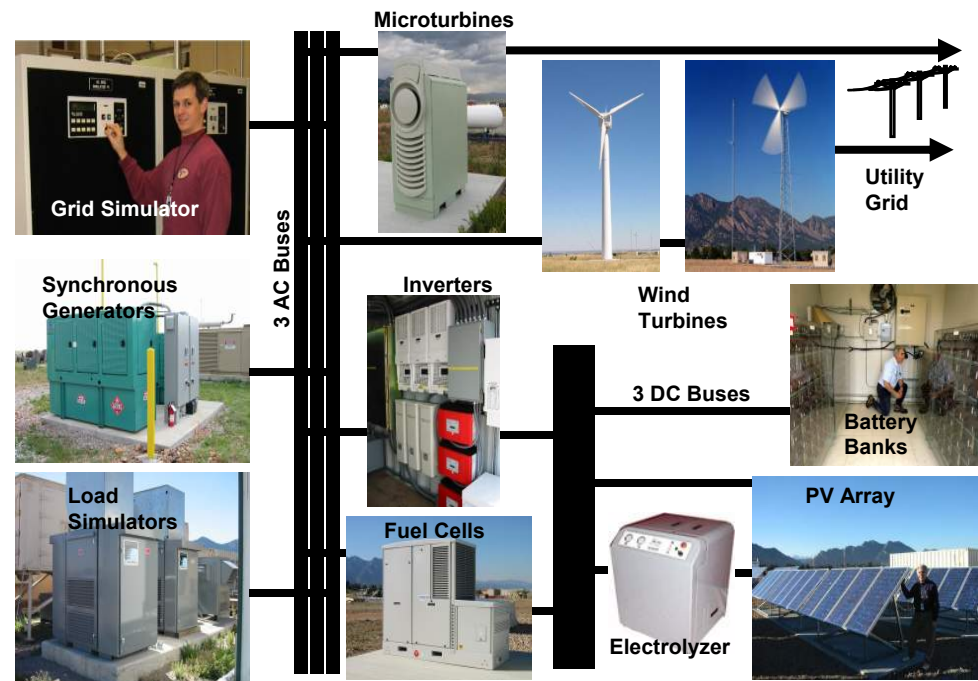


Renewable Electricity at Scale

Focus on Key Barriers

Grid integration/Interconnection Technology

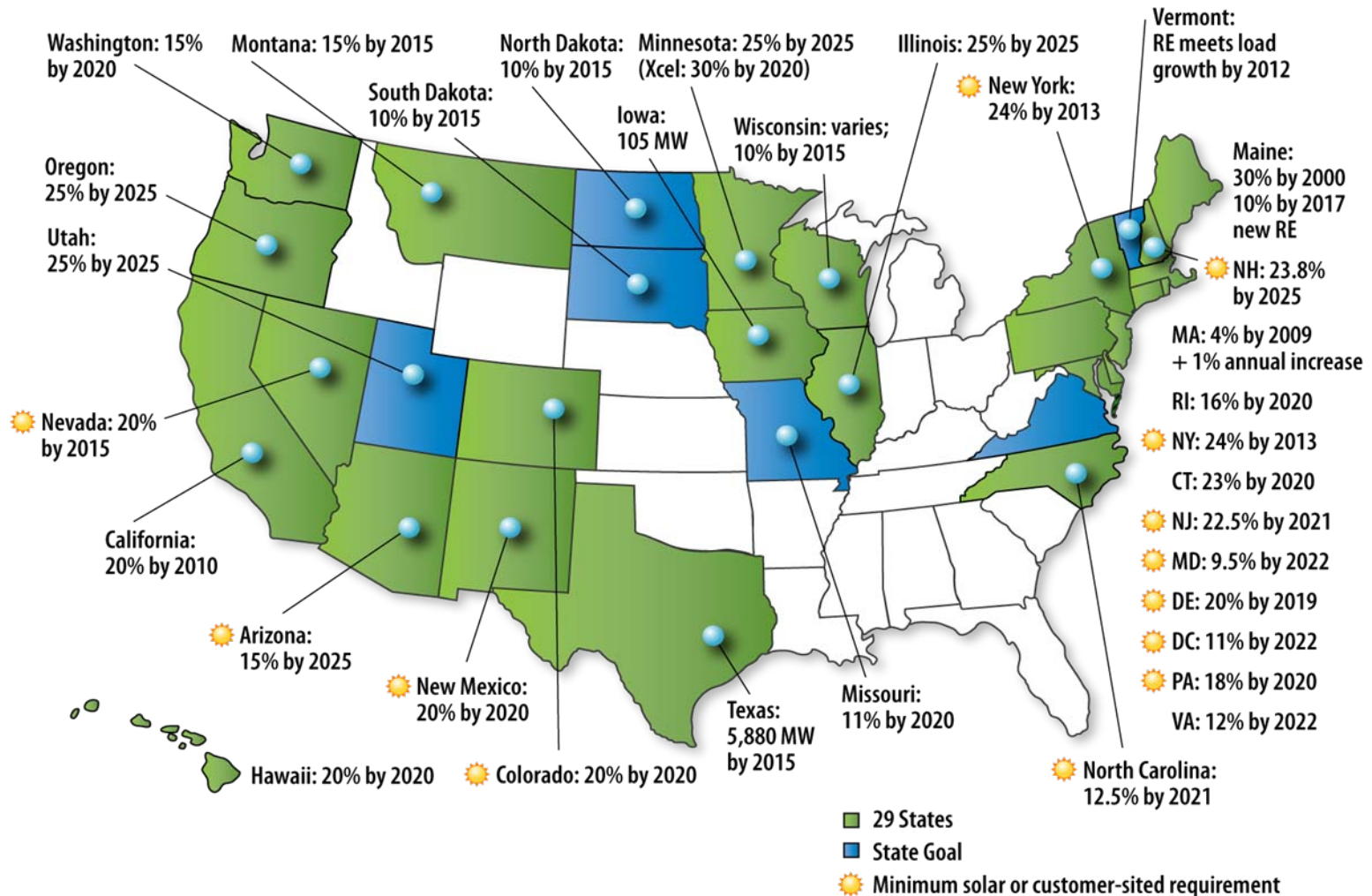
Reliable Operation at High Penetration



An Integrated Approach is Required

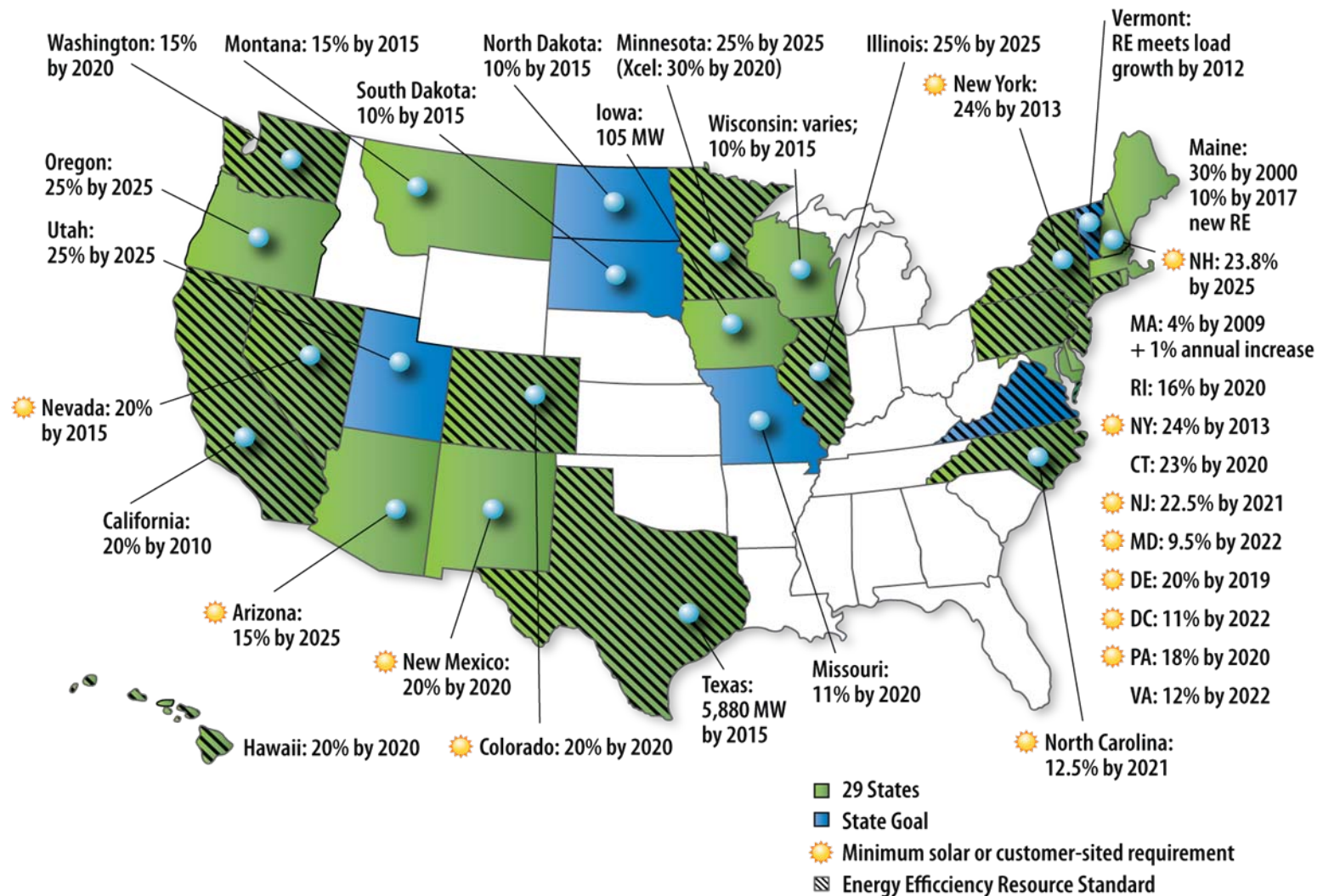


Renewable Portfolio Standards



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Energy Efficiency Resource Standards



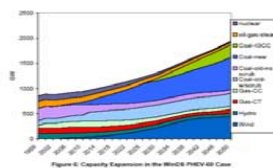
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Strategic Energy Analysis

Technical and economic analyses to advance understanding of technology value in context of dynamic markets, policies, energy resources/loads, and infrastructure.

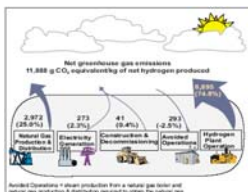
Impact Analysis

Analyze benefits and impacts of programs, portfolios, and policy options



System

Analyze system performance and technology interfaces in the context of the overall system



Technology/Component

Analyze technology and component performance and cost



Resource

Assess resource availability and characteristics

Increasing Attention to Carbon Mitigation Potential Analysis



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